RESEARCH SUMMARY AND ANALYSIS

National Fire Coordination Study

U.S. DEPARTMENT OF AGRICULTURE/FOREST SERVICE/DIVISION OF FIRE CONTROL

RESEARCH SUMMARY AND ANALYSIS

Analysis and Report

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I. INTRODUCTION

The Forest Service is currently conducting a National Fire Coordination Study for the Office of Civil Defense, Office of the Secretary of the Army. The objective of the study (Project 229) is to develop guidelines and make recommendations to OCD concerning ways to effectively organize Federal, state, local, and private fire services to handle mass fire emergencies resulting from enemy attack. Ability to effectively cope with the fires resulting from such a disaster could be closely related to the ability of the United States to survive as a nation.

The NFCS task force will prepare an Analytical Report for OCD as the first phase of the study. This Analytical Report will describe the magnitude of the nuclear fire problem using the latest information available, and will form the basis for determining the course of action for Project 229 during the remainder of the study. The Analytical Report will recommend, among other things, feasible alternative courses of action for the OCD fire defense program. Cost-effectiveness and impact analysis will be made for each proposed alternative.

Recommending alternative courses of action has required synthesis and analysis of pertinent available data developed by the study team including:

1. Findings of pertinent research.
2. Conclusions and recommendations from Combined Mutual Aid and Command Studies.
3. Conclusions and recommendations from the Combined Fire Analysis.
4. Findings from the review of pertinent research recommendations.
5. Effects of possible nuclear attacks on fire service capabilities and related resources.
6. Summary of ideas and suggestions developed at Fire Service Briefing Meetings. (Chicago, Los Angeles, Portland, Oreg., Memphis, and Boston).

This document is concerned with extracting the operational guidelines from the findings of pertinent research (Item 1 above) so that they can be used to develop a coordinated plan for prevention and control of nuclear attack fires.

II. THE PROBLEM

Much research and study has been devoted to the effects of nuclear weapons on the population and resources of this country. As a result of past research, reasonably good descriptions are available of the effects of fallout and blast on populations, structures, shelters, and resources. Describing fire effects, identifying

fire protection measures, and solving the problem of what to do to achieve effective control of fires that might occur from nuclear attack has received relatively little attention. This lack of attention probably stems from the fact that describing fire, predicting fire behavior, and determining fire effects, even on small experimental fires, is a difficult technical problem. Independent investigations have produced many conflicting results. Conclusions and recommendations developed are frequently in disagreement. For example, there is currently widespread disagreement concerning the importance of fire as a major destructive agent arising from a nuclear attack. On the one hand are those that recognize fire as being the primary destructive force following an enemy attack; on the other, are those who maintain just as emphatically that fire will be only a minor contributing factor in causing widespread death and destruction of property.

The research reviewed in this report acknowledges the importance of fire as a destructive force. Many of the findings from this research can contribute to more effective fire prevention and control. The problem then is to (1) identify the promising research conclusions and convert these to operational guidelines that can be used in developing a nationally coordinated plan for handling large fire disasters and (2) identify areas where research is needed to discover new information or resolve conflicts in current findings.

III. OBJECTIVES AND SCOPE

Using the research documents suggested by OCD, plus additional selected reports and information pertinent to the study. (Appendix A) The objectives of this Research Summary and Analysis are to:

1. Summarize pertinent research conclusions so they can be evaluated in terms of Operational Guidelines for use during the National Fire Coordination Study.

2. Review pertinent research currently underway that may have application in later stages of the National Fire Coordination Study.

3. On the basis of research reviewed, recommended to OCD areas where additional research is needed to improve the current state of knowledge and ability to cope with the fire situation following nuclear attack.

This report is not intended to be a complete review of the thermal threat of nuclear weapons. Rather it is an attempt to review as much significant research as possible prior to preparation of the Analytical Report with the aim of continuing the review of research throughout the study. An effort was made to study each conclusion extracted from the research reports and wherever possible, state what it means OPERATIONALLY (Operational Guidelines) as it

applies to the objective of Project 229. Where there were conflicts of opinion, or available research results were incomplete, an element of judgment was exercised by the study team to develop the Operational Guidelines from research conclusions.

The Conclusions are listed by functions in Appendix B through L and are taken directly from the research reports listed in Appendix A. Each conclusion is coded to Appendix A, so that the reader can determine the source of the individual conclusion.

The Operational Guidelines listed in Section V, and the Recommendations listed in Section VI, reflect the best efforts of the author of this report to make operational use of current research information.

IV ANALYSIS

There are over 200 conclusions in all, extracted from 18 research reports dating from 1959 to 1964. These conclusions fall into ten broad functional categories (Appendixes B through L). These groupings are intended to sort the conclusions so the problem solver can readily relate them to his problem. The groupings roughly follow the sequence of events which would occur following an assumed nuclear attack.

Ten research progress reports and reports of meetings and discussions with key research people also were reviewed (Appendix A). Conclusions from these sources are not listed in this report but were considered in making the analysis and arriving at the conclusions and recommendations.

Some duplication may be found in these conclusions. There are some conflicting conclusions but overall there is a surprising amount of agreement among them. All are important. There are some research conclusions or groups of conclusions that are particularly germane to the National Fire Coordination Study. These are discussed by functional categories in the following paragraphs.

Attack Assumptions (Exhibit B, Appendix)

(Note: A discussion of attack and targeting assumptions is desirable to complete the frame of reference in which the National Fire Coordination Study is operating. Item 5, in Section II of this report, mentioned that an attack analysis will be made as part of the National Fire Coordination Study. One or more hypothetical nuclear attack patterns will be superimposed on representative American cities to indicate the range in magnitude of fire disasters that the task force should plan for. Attack assumptions will be based on the latest information available).

Attack assumption conclusions indicate that there are at least five possible types of nuclear attack: (1) First strike (deliberate), (2) second strike (retaliatory), (3) pre-emptive (strike from fear), (4) accidental, and (5) n^{th} country (small nation). The deliberate type of attack is likely to involve little or no warning to the United States; whereas, the retaliatory attack would involve some or much warning, depending on the situation. The accidental attack is the most difficult to evaluate since there would be no warning, and the targeting as well as the timing would be essentially of a random nature. (L) *

Targeting of the deliberate attack may be either counterforce (against bases), population, or mixed; whereas, a retaliatory attack would probably involve only population targets. Targeting for the accidental attack would be of a random nature and hence would not be predictable. (L)

(*Letters refer to specific references listed in Appendix A)

Probably the deliberate attack would lead to optimum damage, including fire, since the enemy likely would plan the attack to maximize all types of damage, fire, blast, and fallout. Also, there would be little or no warning. (L)

There appears to be general agreement that the effect of the choice of targets on the threat from fire cannot be ascertained with any reliability at this time. This is because the physical principles of ignition and fire spread by nuclear weapons are not fully understood. (L)

There is some disagreement among the experts as to the capability and effects of the Soviet nuclear weapons systems. Some credit them with the ability to put into orbit and deliver superbombs of 100 Mt. or even 1,000 Mt. yield. (L) However, the majority feel that the maximum weapon size we will have to contend with for the present and in the near future is 20 Mt. or lower yield. This is because of delivery and aiming problems with the superweapons. (Q)

Recent Soviet developments in rocketry for manned space flights suggest that they are rapidly developing their delivery capability for larger weapons, however.

In a counterforce attack, many of the targets probably will be our hardened missile bases. Burst at low altitudes to maximize blast effects probably would be used against these targets. On the other hand, population attacks probably would consist of bursts at high altitudes since this tactic would tend to maximize fire effects. The density of ground zeros in the target area and whether ground zeros are superimposed also would have a bearing on fire effects produced.

Modification of Nuclear Thermal Radiation by the Environment (See Appendix C)

The attack assumptions used in the impact anlaysis include multi-megaton yield weapons detonated at altitudes ranging from the stratosphere to near the ground. Height of burst has a large effect on the disposition of the thermal energy produced by a weapon and on the fire effects produced on the target. Furthermore, the thermal radiation produced can be drastically modified by the intervening atmosphere and weather conditions. These effects are very important to the present study. In nuclear detonations at extremely high altitudes at least half of the energy produced is radiated to outer space; whereas, in atmospheric shots, the loss is not so great because of scattering. (L) The thermal effects of ground and low altitude bursts generally are well understood by virtue of the weapons effects tests conducted in past years. The thermal effects for extremely high altitudes (more than 31 miles) and outerspace shots are known by virtue of theory only. However, the intermediate altitudes are difficult to explain and the empirically-derived

scaling laws are not too reliable. Also, the understanding of the thermal pulse shape at altitudes up to 31 miles is not too great. The foregoing suggests that at present the prediction of ignitions from shots at intermediate altitudes may not be too reliable. (L) However, intermediate attack altitudes appear to be optimum for achieving certain fire effects.

Atmospheric transmissivity is one of the greatest sources of error in predicting initial ignitions at the target. (I) Estimates of the amount of thermal radiation reaching locations 20 to 40 miles from a nuclear detonation, especially in urban areas, can vary by a factor of 10. (Q) This is largely because of differences in estimating visibility or opacity of the atmosphere.

Although the problem is rather complex, a few generalizations are possible that may help to understand the phenomena:

a. On clear days the ignition radius for a 100 Mt. detonation at 30 miles altitude will be about 65 miles. (Q)

b. A layer of high, thin clouds could reduce the ignition radius for a 100 Mt. detonation at 30 miles altitude from 65 miles to 30 miles; to 10 miles by a layer of lower, dense clouds. A thick layer of very dense clouds could preclude thermal ignitions entirely. (Q)

c. On fairly clear days, air burst nuclear weapons of megaton yields will ignite kindling fuels at ranges where the blast overpressure is between 1 and 3 p. s. i.; an average of 2 p. s. i. (Q)

NOTE: This is a considerably lower over-pressure for ignition than for nominal yield atomic weapons.

d. The maximum ignition radius for weapons up to 20 Mt. yield is about 25 miles. (Q)

e. Variations in atmospheric transmission can cause the ignition radius for dry pine needles having ignition requirement of 10 cal. / $cm.^2$ for 10 Mt. burst at 30,000 feet to vary from less than one mile for low visibility conditions, to approximately 20 miles where visibility is 50 miles. (L)

There is disagreement concerning the claim that superbombs detonated at satellite altitudes could set fires over several states. A large proportion of the energy would probably be lost to outer space in these situations. A very small percentage would arrive at a ground target.

Response of Target Elements to Direct Nuclear Thermal Radiation (See Appendix D)

The discussion in this section overlaps somewhat the material in the previous section. It deals primarily with the nature of kindling fuels and estimates of their ignition thresholds.

Concerning ignitions from nuclear attack, the only effect of genuine concern appears to be the ignition of thin cellulosic kindling fuels, i.e., materials igniting at less than about 20 cal./cm^2. In this category are such urban fuels as newspapers and cloth and rural fuels such as pine needles, leaves, and grass. (K)

The radiant exposure required to ignite a material is a function of exposure duration, i.e., the efficiency depends upon rate of delivery of energy. Other important single factors affecting ignition are the area of exposure and the geometry (position) of the exposed material. (K) Radiant exposure values for sustained ignition of typical kindling fuels are on the order of 5 -10 cal./ cm^2 but can vary widely from these values. (D) (K).

However, at the present time there is insufficient yield altitude scaling information to permit detailed simulation of thermal pulses from high-altitude bursts. There are also technical difficulties involved in simulating the irradiance levels from burst at these altitudes in the laboratory. (K) Actual weapons effects tests could help solve these problems but are not permitted at present.

One attack possibility that would further complicate estimates of ignitions would be two or more weapons arriving on the same target at short intervals. Radiant exposures might be additive if the arrival interval were short. (L) In any event, charring from the first pulse is likely to predispose the material to ignition by the second pulse.

These conclusions point up the uncertainties involved in trying to predict ignitions from multi-megaton weapons detonated at high altitudes.

Target Vulnerability (See Appendix E)

There is considerable evidence that nuclear weapon fires will be a major source of damage in future nuclear wars. (D) (J) Also, that the ratio of damage by fire to damage by blast increases with weapon yield. (D) From a fire standpoint, the high-altitude thermal attack with a high yield weapon (100 Mt.; 250,000 feet) is most destructive followed by airbursts (5 Mt.; 8100 feet) and surface bursts (5 Mt.) in that order. (J)

Ground bursts would probably be used to destroy hardened targets (counterforce attack). This would reduce the area of initial ignitions. (L) It would also reduce the ignitions in another way in that most hardened targets are more or less remote from population centers and located in areas where ignition points are relatively scarce. Low altitude or surface bursts increase the fallout produced, however.

Urban areas are quite vulnerable to fire from a nuclear thermal pulse. (K) However, there is disagreement on the relative importance of interior and exterior kindling fuels as fire raisers. Available information is inadequate concerning the actual distribution of kindling fuels in urban areas. For instance, practically no information exists concerning the importance and statistical distribution of vegetation near structures. (L)

Evidence from World War II seems to support the contention that in future nuclear wars the thermal pulse will be an important fire raiser. (D) In general, fire risk was greater for incendiary bombing raids than for high explosive bombing raids. At Hiroshima and Nagasaki the blast damage area extended farther out from ground zero than did the main fire area, yet there were only isolated fires in the area affected only by blast. There appears to be little direct evidence to support the contention that most of the fires in Hiroshima were caused by blast damage. (P)

There are several points of agreement with respect to interior ignitions from the thermal flash in urban areas. Window drapes or curtains increase the chances of interior fires and streets perpendicular to the direct line of flash will suffer the maximum numbers of interior ignitions. (P)

Interior fuel ignition is relatively insensitive to the weather; whereas, the ignition and burning of exterior fuels depends heavily on the weather. Shielding is an important factor in determining ignition possibilities following the heat flash. It also affects the survival rate of people. (P) It has been estimated that for the average American city, the high altitude incendiary weapon would be effective 1/3 of the time, partly effective 1/3 of the time, and ineffective 1/3 of the time, based upon the frequency of cloudy days. (Q)

Concerning shelter buildings, one investigator concludes that they can be ignited during fallout periods from nearby burning structures or accidental fires. In fact, most shelter structures would be in danger of fire from ignition of buildings close by. Shelter buildings may be classified as: (1) Fire limiting, (2) suppression dependent, and (3) untenable. (R)

The pattern of fallout without the occurrence of mass fires may be predicted with a reasonable degree of accuracy. It now appears, however, that the convection column from a mass fire can change the normal fallout pattern, perhaps drastically. Theory indicates that this is possible, and small wind tunnel experiments have demonstrated the effect. No large scale experiments are available. Experimental results are not directly applicable to open air conditions, however. (C)

Because of the characteristics of fire spread and the large ignition areas, the accuracy of the nuclear weapons is not a critical factor in the weapons effectiveness in setting fires. A weapon can miss the target several miles without materially affecting the ultimate fire damage produced. (L)

Fire Development and Spread (See Appendix F)

Nuclear weapon attacks on American cities may start many primary and secondary fires. (D) (Q) Under certain conditions of fuel, weather, topography, and targeting, these fires will coalesce into mass fires such as firestorms and conflagrations. The mechanisms of fire spread, coalescence, and development of mass fires is largely unknown at the present time. The state of the art as reflected by research report conclusions is summarized briefly below.

Conclusions indicate that, in most cases, fire in structures would not be started directly in thick, solid material by the thermal pulse; rather, it would develop from ignited kindling fuels in proximity to or within the structures. Also, that primary fires will be a significant factor in the initiation of mass fires in American cities as a result of nuclear weapon attacks. (D) (L) Secondary fires also will be started due to blast effects, but most reports conclude that fires from this source will be less numerous than primary fires. One analyst reference's dissention to this opinion. (D) Another report concludes that the incidence of secondary fires (from blast) was probably not high enough to cause a firestorm even in such a flammable city as Hiroshima. (P) Obviously, there is far from complete agreement on the importance of primary and secondary fires resulting from nuclear attack.

There is still very little known about the coalescence of fires into mass fires. However, several points are reasonably well established:

a. Densities of ignition points in the initial ignition radius decreases with distance from ground zero, and varies with type and distribution of fuel at a given distance. This affects fire growth. (L)

b. Mass fires are most likely to develop in heavily built-up urban areas. Some investigators feel that firestorms could not develop in rural areas because of too low fuel volumes. (Q)

c. The conditions most favorable to mass fires are densely built-up urban areas, high density of ignitions, and low wind speed. (Q)

d. In cities, fire spread depends more on spacing and type of construction than on weather. (E)

e. There is evidence to indicate that a potential ignition area cannot be considered as a single fire area engulfed in flame, since the controlling factors are the occurrence and size of the fuel area rather than the ignition range of the weapons. (Q)

Concerning the spread of free burning fires, conclusions indicate that inadequate information is available on the physics of large-scale fire spread. The following points are proposed for consideration:

a. Fire behavior in uninhabited areas following nuclear attack would be basically no different from the behavior of wildland fires in peacetime. (E)

b. City fires spread at about the same rate as forest fires. (E)

c. Fire spread over periods of 6 hours or longer is much slower than is popularly assumed. (E)

d. Over long periods of time, fires travel fastest over level ground; upslope, next fastest; downslope, slowest. (E)

e. Rate of spread depends on the length of time over which the spread is measured. (E)

f. On large fires, the head fire moves, on the average, 3 times the rate of the flanks and 7 times as fast as the rear. (E)

g. Once a mass fire is started, its spread is dependent on winds, other climatological factors, and the distribution and condition of heavier fuels. This is true both for urban and rural areas. (L)

Results of research on full scale simulated urban fires are reported by one analyst, who concludes:

a. Extreme temperatures may be reached in two or three minutes following multiple ignitions in a prepared fuel bed. (F)

b. Temperature may account for behavior differences between large and small fires. (F)

c. For some fires, fire spread from radiation is of minor importance. (F)

d. Fires (convection columns) physically block ambient air flow. (F)

e. Eddy circulations are important in the development of fire whirlwinds and possibly, firestorms. (F)

In the United States, critical periods of fire weather appear to be associated with a relatively few synoptic weather patterns and types. The periods when weather conditions favor fast-spreading, high intensity fires can be identified. Recent climatological research has produced snow cover probability maps and monthly levels of fire danger for extended periods. These data will be useful for fire defense planning, particularly for urban areas. (N)

Fire Spread and Damage Assessment Models (See Appendix G):

Nuclear fire damage assessment models have been under development in the United States for at least seven years. One early "model" was the "1957 Forest Damage Assessment" study made by the Forest Service. It consisted of a set of tables that showed the probable distance a fire would spread in four cardinal directions in homogeneous forest fuel types by months in the United States, assuming no control action. Spread distances were estimated by experienced fire control people.

A few years later, a private research organization refined the system so that total area of burnout for various weapon sizes and targeting could be extracted from tables. A university computing center began working with the same data to refine the system and put the "model" on a computer. This was completed recently and is the system that has been used to help prepare the Analytical Report as a part of the National Fire Coordination Study. "Flame I," as the model is known, is a damage assessment program to apply soon after a nuclear attack and for hypothetical fire spread studies. It estimates which land areas, on a nationwide basis, would be affected by fire spread following attack. It does not attempt to predict fire intensity or damage resulting from the fire. (G)

Relevant factors used by Flame I in considering the extent of fire spread are:

1. Weapons information.
2. Geographical information (including fuels and barriers).
3. Weather information.

Weapons information must include:

1. Geographical position of ground zero.
2. Weapon yield.
3. Height of burst.
4. Month detonated.

The model attempts to predict fire spread from an attack by estimating for each grid rectangle on a map the probability that it is burned. Weather, fuels, and fire barriers are considered along with weapons information. (G)

An advanced fire spread model based on a new approach is nearing the testing stage and may have application in the later stages of the National Fire Coordination Study. The work is being done by the same firm that improved the "1957 Forest Damage Assessment" study model. This model is based on actual rate of spread data extracted from numerous case histories of large, free-spreading urban fires and forest fires. Rates of spread are related to the controlling variables of weather, fuels, and topography. Theoretical contagion models used extensively in public health work are adapted for estimating rate of spread as well as area of burnout at any desired instant.

A research organization located in the Chicago area also is developing a fire spread model, based primarily on theoretical fire spread considerations. It needs to be tested against actual data but may have possibilities for future use in the National Fire Coordination Study.

It can be said of all models, completed and on the drawing board, that they do not consider the total fire damage which would be created under various assumed targeting doctrines. They consider only attack by a single weapon.

The foregoing discussed only fire damage assessment models. Models have been developed to estimate other types of damage including fallout and blast damage. In general, these models are further advanced than the fire damage models. Other types of models will not be discussed here.

Vulnerability of Humans (See Appendix H):

If the population can take advantage of available shelter spaces, many of those on the fringe of the blast would likely survive a nuclear attack. Past experience indicates the rate of development of large fires has been sufficiently slow to permit control, or movement of people to areas of relative safety. However, thermal characteristics of current weapons indicate a potential for ignition radii large enough to preclude effective evacuation measures until after the fires have subsided. Judging from the Hamburg, Germany mass fire experience, many people in fire resistive shelters that could be closed to exclude the lethal heat and gasses survived. (Q)

In Germany, a greater loss of life resulted from the firestorm raids than high explosive or non-firestorm raids. In every case where firestorms were experienced, the loss of life was heavier than in raids that involved mostly blast effects and high explosive bombs. (P) Findings generally agree that fire will be a significant factor in causing injuries, loss of life, and destruction of property immediately following a nuclear attack. Firestorms may develop in populated areas. (J) Fallout shelter occupants will be exposed to fire from several sources. (R)

It is well established that lethal concentrations of noxious gasses occur in the combustion zone of most fires. Extreme concentrations of carbon monoxide are to be expected in large-scale fires burning out-of-doors. (B)

Important considerations for installing and operating shelters include the following:

1. Home shelter vents located just outside the residence will be of little value, since toxic gasses may be found in these locations. (B)
2. Shelter vents may not need to be closed for more than an hour or so during mass fires if they are located so that they will not be covered by rubble. (B)
3. If shelter ventilation systems are to be operated during a fire, shielding of intake vents from radiant heat should be considered to insure passage of cool air. (B)

Protection of structures over shelters will be critically important in nuclear attack situations. Occupants may not be able to emerge to help fight incipient fires because of fallout. This is considered further in the next section.

Countermeasures (Appendix I):

Pre-attack measures must be taken to reduce the number of fires resulting from nuclear attack. Fire vulnerability of population centers can be lessened by extensive pre-attack planning and training to implement the self-help firefighting concept. (K) In planning a fire defense program, the removing or covering of ignitable materials is equally important as the development of fire control capabilities. (Q) A general cleanup campaign (both inside and outside structures) would reduce the ignition points and, hence, the probability of the development of mass fires. (L)

Promising measures in addition to cleanup campaigns are thermotropic and tenebrefic coatings for windows and smoke screening systems. (J)

Other measures that may have possibilities for mitigating the severity of the fire problem include:

a. Ordinances against littering.

b. Improved building standards.

c. Raze dilapidated structures.

d. Coat exterior kindling points.

e. Sprinkler systems.

f. Provide and equip fallout and blast shelters for the populace.

g. Fine mesh screens on windows.

Detailed and extensive cost-effectiveness studies of active and passive fire defenses will be necessary before their effects upon Civil Defense policy and doctrine can be adequately evaluated. (J)

Organizing To Suppress Post-Attack Fires (Appendix J):

The reports generally agree that professional urban fire departments will not have the resources required to effectively fight the post-attack fires, and that the cost of maintaining conventional fire-fighting forces adequate to handle any post-attack fire situation would be prohibitive. It appears inescapable that assistance from the general public, properly trained and equipped, is necessary to combat fires resulting from attack. (J)

Another source states that organized public firefighting agencies, with or without assistance from the civilian population, are incapable of suppressing a going urban mass fire. Mass fire must be prevented by extinguishing building fires before they can join with other fires. (M) This is not to say, however, that the existing fire services should not be organized to the fullest to cope with the mass fire situation. This is the primary objective of the National Fire Coordination Study.

One research study has shown that room fires consisting of burning furniture items can be controlled by trained individuals properly equipped and operating in pairs. (M) Teams must act rapidly because, due to the possibility of radioactive fallout, only a relatively short period of time may be available to extinguish the multiple ignitions following the nuclear attack. Maximum utilization of effort, with emphasis on minimum use of extinguishing media and equipment, will be important. The five-gallon stirrup pump was found to be the most satisfactory piece of self-help extinguishment equipment. Specific self-help measures suggested include:

1. Equip and train building tenants for self-help firefighting.
2. Train the citizenry in fundamentals of firefighting.
3. Provide inducements for training.
4. Make teams self-sufficient.
5. Standardize on simple, low-cost equipment.

6. Provide sources of supplemental water.
7. Install more radio channels.
8. Equip fire suppression groups with radiological monitoring equipment.

The problems of organization for large fire emergencies, including mutual aid and command, was also considered. Several conclusions bearing on this problem are listed in Appendix J. They will not be covered here because they are being covered in greater detail in other phases of the National Fire Coordination Study which is primarily concerned with organization and command.

Suggestions For Additional Research (Appendix K):

As was expected, many of the conclusions from the research report specifically suggested additional research. Other conclusions inferred that more research was needed.

Several conclusions in one report suggest that wildland fuels can be arranged and burned so as to simulate many urban conditions. Field scale fires can be replicated when tests are conducted under like air mass conditions and with similar fuels. He points out that some observations during field tests suggest conditions that are not evident in small scale or laboratory fires. The simulated urban tests completed to date are not considered mass fires due to their limited size, but larger test plots are available for burning that might produce mass fire effects.

One report includes a group of twelve conclusions suggesting additional research (Appendix K). These conclusions are based on an exhaustive survey of the thermal threat of nuclear weapons and cover practically every aspect of the problem. They are worthy of careful study.

Miscellaneous (Appendix L):

One study presents four conclusions dealing with developments in infrared aerial scouting equipment and techniques for fire surveillance and mapping. Present equipment is sufficiently accurate to map the fire perimeter with respect to terrain features. The system has the capability to penetrate dense smoke covering large areas. Its potential for mapping fire areas in nuclear disasters is obvious. (H)

V. OPERATIONAL GUIDELINES:

1. At present, the prediction of ignitions from large yield bursts at intermediate altitudes is not reliable.

2. Estimating visibility and atmospheric transmissivity are the greatest sources of error in predicting initial ignitions at the target if yield and height of burst are known.

3. Fire will be a significant factor in causing injuries, loss of life, and destruction of property following a nuclear attack.

4. Numerous small fires will occur following an attack if a sufficient level of thermal energy reaches kindling fuels.

5. Primary ignitions will usually be more important than secondary ignitions in the ultimate development of mass fires.

6. At certain times of the year, forested areas are quite vulnerable to fire from a nuclear thermal pulse.

7. Interior fuels are relatively insensitive to weather and will ignite readily from direct exposure to a thermal pulse of sufficient magnitude.

8. Shielding is an important deterrent to initial ignition following a thermal pulse.

9. Precise delivery accuracy is not important for nuclear weapons used to ignite large areas.

10. Urban fire departments will be wholly inadequate to effectively fight post-attack fires.

11. Fire spread models currently available for urban or rural areas do not presently consider the total fire damage picture but only the damage resulting from attack by a single weapon.

12. Information is lacking on mechanism of fire spread in urban and rural areas, and the coalescence of fires into a mass fire situation.

13. Mass fires must be prevented by extinguishing building fires before they can join together.

14. Known information concerning coalescence of fires into mass fires is stated operationally in items a. to e., page 20, the Analysis section of this report.

15. Known information concerning mechanism of large scale fire spread is stated operationally in items a. to g., page 21, in the Analysis section of this report.

16. Weather patterns that favor fast-spreading, high intensity fires in rural fuels are known and may be predicted with fair degree of accuracy.

17. Immediate effective evacuation measures may well be impossible in situations where high yield weapons produce large areas of initial and secondary ignitions.

18. Fallout shelter occupants may be exposed to fire from several sources and must therefore be given adequate protection from fire until evacuation is possible.

19. Shelters that are under or adjacent to, heavy fuel loading may become untenable if fires are not controlled.

20. Elimination of toxic gases and insuring adequate ventilation are two important problems to solve in providing safe conditions for shelter occupants.

21. Convection columns resulting from mass fires may alter the expected fallout pattern.

22. Adequate pre-attack planning will measurably reduce the number of fires resulting from enemy attack.

23. The existing fire services could provide effective leadership in training prior to, and command during, mass fire situations.

24. A properly trained and equipped general public will be needed to combat initial and secondary ignitions resulting from enemy attack.

25. Room fires can be effectively controlled by teams of trained individuals acting quickly following nuclear attack.

VI. RECOMMENDATIONS:

In order to make the most effective use of these operational guide lines in the National Fire Coordination Study we recommend that:

Operational

1. Steps be taken to suppress primary and secondary fires within a few minutes after ignition to prevent possible coalescence into mass fires.

2. We develop positive pre-attack planning measures to reduce the number of fires resulting from enemy attack.

3. More attention be given to adequate fire protection for shelters through pre-attack planning, and post attack efforts, to keep the shelters from becoming untenable because of fire.

4. We develop citizen self-help fire suppression measures to supplement the efforts of existing fire services.

5. Better use be made of available weather information to help in pre-attack planning for large fire emergencies.

Research

1. Research be continued to better identify the complex relationships between weapon effects and the variables of weapon yield, height of burst, atmospheric attenuation, pulse shape, pulse duration, season of year, and fuel ignition characteristics.

2. Research be continued to improve the basic input data for urban and rural fire spread models.

3. Research be conducted to provide more adequate shelter fire protection in existing shelters, and in shelters to be constructed.

List of Appendixes

VII APPENDIX

A. Research Documents Reviewed, and Progress Reports and Interviews.

B. Conclusions: Attack Assumptions.

C. Conclusions: Modification of Nuclear Thermal Radiation by the Environment.

D. Conclusions: Response of Target Elements to Direct Nuclear Thermal Radiation.

E. Conclusions: Target Vulnerability.

F. Conclusions: Fire Development and Spread.

G. Conclusions: Fire Spread and Damage Assessment Models.

H. Conclusions: Vulnerability of Humans.

I. Conclusions: Countermeasures.

J. Conclusions: Organizing to Suppress Post-Attack Fires.

K. Conclusions: Suggesting Additional Research.

L. Miscellaneous Conclusions.

Appendix A - Research Documents Reviewed
(Sources of Conclusions)

Source Code	Source Document
A.	A National Method For Estimating Total Burnout Following Nuclear Attack, U. S. Forest Service, Washington, D. C., 1961 (1957 original)
B.	Broido, A. and McMasters, A. W., Fire Exposure of People in Shelters. Reprint, NFPA Quarterly, October 1961.
C.	Broido, A. and McMasters, A. W., The Influence of a Fire Induced Convection Column on Radiological Fallout Patterns. Technical Paper No. 32, PSW Forest and Range Experiment Station, U. S. Forest Service, 1959.
D.	Brown, F. W., Ignition of Fires and Fire Spread by Thermal Radiation, U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, June 1962.
E.	Chandler, C. C., A Study of Mass Fires and Conflagrations, Research Note No. 22, PSW Forest and Range Experiment Station, U. S. Forest Service, 1963.
F.	Countryman, C. M., Mass Fire and Fire Environment Progress Report, PSW Forest and Range Experiment Station, OCD Project 32 (2521E), 1964.
G.	Flame I Fire Spread Simulation Model, University of North Carolina, Computation Center, Special Project Branch, N. R. E. C. Technical Report No. 21, January 1961.
H.	Hirch, S. N., Infrared As a Fire Control Tool, Intermountain Forest and Range Experiment Station. Reprint from Proceedings, Western Forestry and Conservation Association, December 1962.
I.	Jewell, W. S., and Willoughby, A. B., A Study to Analyze and Improve Procedures for Fire Damage Assessment Following Nuclear Attack, Broadview Research Corporation, Part I, Final Report, October 1960.

J. Lommasson, T. E., Nuclear War and the Urban Fire Problem, The Dikewood Corporation, DC-TN-1040-1, Addendum No. 3 to Second Quarterly Report Contract No. OCD-PS-64-16 (An Interium Report) February 20, 1964.

K. Martin, S. B., Primary Effects of Nuclear Weapons, U. S. Naval Radiological Defense Lab., paper presented at Tripartite Technical Cooperation Program - Thermal Symposium, England, October 5-9, 1964.

L. Rogers, J. E., and Miller, T., Survey of the Thermal Threat of Nuclear Weapons, Unclassified Version, Stanford Research Institute Project No. IMU-4021 for OCD, November 1963 (second printing May 1964)

M. Salzberg, F., Maatman, G. T., and Vodvarka, F. J., An Approach to Trans-Attack Fire Suppression in Urban Areas, Illinois Institute of Technology Research Institute, Project No. N-6005, March 1964.

N. Schroeder, M. J., et al. Synoptic Weather Types Associated with Critical Fire Weather, PSW Forest and Range Experiment Station and U. S. Weather Bureau, OCD Contracts OS-62-143 and PS-64-24, 1964.

O. Small Community Firefighting Resources for Major Fire Disasters, Bio-Dynamics Inc., Third Quarterly Progress Report, Contract No. OCD-PS-64-39, 1964.

P. Stanbury, G. R., Ignition and Fire Spread in Urban Areas Following a Nuclear Attack, paper presented at Tripartite Technical Cooperation Program - Thermal Symposium, England, October 5-9, 1964.

Q. Strope, W. E., and Christian, J. F., Fire Aspects of Civil Defense, Department of Defense, Office of Civil Defense, Research Report No. 9, May 1964.

R. Varley, R. B., and Maatman, G. T., Shelter Fire Vulnerability - Specific Fire Limiting Activities for Occupants, Illinois Institute of Technology Research Institute, Project No. N-6005, September 6, 1964.

Appendix A (Cont.) - Progress Reports and Interviews

Note: The following list includes references to research underway relating to the National Fire Coordination Study. Conclusions and recommendations from these sources are not included in the body of this report but were considered in making the analysis and arriving at overall conclusions and recommendations.

Dieterich, J. H., Report: Meeting with National Fire Protection Association and Factory Mutual Research Corporation (memo report to W. R. Moore, 1360 (Meetings) of October 26, 1964)

Dieterich, J. H., Report: Discussion with Disaster Research Center, Ohio State University, (memo report to W. R. Moore, 1360 (Meetings) November 6, 1964)

Dieterich, J. H., Report: Meeting with Illinois Institute of Technology Research Institute, (memo report to W. R. Moore, 1360 (Meetings) November 17, 1964)

Pfung, P. V., and Willoughby, A. B., Prediction Models for Fire Spread, Symposium Paper, United Research Services, April 1964

Willoughby, A. B., and Pfung, P., Rate of Spread Data in Urban Fuel, Second Quarterly Progress Report, URS 641-2, United Research Services, June 1964

Pfung, P. V., and Willoughby, A. B., Fire Spread Vulnerability of Resources, Third Quarterly Progress Report, URS 641-3, United Research Sources, September 1964

Pfung, P. V., and Willoughby, A. B., Acquiring and Using Weather Data in Fire Spread Prediction, Progress Report, URS 641-4, United Research Services, October 21, 1964

Sachs, A., Current and Proposed Thermal Damage Assessments Study, Institute for Defense Analysis. Paper presented at Tripartite Technical Cooperation Program - Thermal Symposium, England, October 5-9, 1964

Smith, J. B., and Cousins, E. W., Fire Hazard to Fallout Shelter Occupants, Final Report, R.M.R.C. Serial No. 15328, Factory Mutual Research Corporation, April 3, 1964

Storey, T. C., Report: Meeting with United Research Services and Stanford Research Institute, (memo report to W. R. Moore, 1360 (Meetings) of November 4, 1964)

Willoughby, A. B., and Pfung, P., Study and Development of Improved Methods for Predicting Fire Spread Following Nuclear Attack, First Quarterly Progress Report, URS 641-1, United Research Services, March 1964

Appendix B - Conclusions: Attack Assumptions

Source Code	Conclusions	Date
L.	The deliberate type of nuclear attack is likely to involve little or no warning to the United States. Very likely it would lead to optimum damage, including fire.	1964
L.	Targeting of the deliberate attack may be either counterforce, population (on an independent target basis), or mixed.	1964
L.	A retaliatory attack would probably involve only population targets with either some or a great deal of warning.	1964
L.	The accidental attack is the most difficult to evaluate since there would be no warning and the targeting, as well as the timing, would be essentially of a random nature.	1964
L.	The effect of the choice of targets on the threat from fire cannot be ascertained with any reliability at this time since the physical principles of ignition and fire spread by nuclear weapons are not fully understood.	1964
L.	It is questionable whether the Soviets presently have the capability to operationally deliver or put in orbit 100 MT weapons, or larger.	1964

Appendix C - Conclusions: Modification of Nuclear Thermal Radiation by the Environment

Source Code	Conclusions	Date
I.	Atmospheric transmissity is greatest source of error in predicting initial ignition.	1960
Q.	Estimates of the amount of thermal radiation reaching locations 20 to 40 miles from a nuclear detonation, especially in urban areas can vary by a factor of 10.	1964
Q.	A layer of high thin clouds could reduce the ignition radius from 65 miles to 30 miles; to 10 miles by a layer of lower dense clouds.	1964
Q.	On fairly clear days air burst nuclear weapons of megaton yields will ignite kindling fuels at ranges where the blast overpressure is between 1 and 3 p.s.i.; an average of 2 p.s.i.	1964
Q	On clear days the ignition radius for a 100 MT detonation at 30 miles altitude will be about 65 miles.	1964
Q.	The maximum ignition radius for weapons up to 20 MT yield is about 25 miles.	1964
L.	It is questionable whether large weapons detonated at high altitudes could set fires over the large areas claimed by some investigators.	1964
L.	In detonations at extremely high altitudes at least half of the energy is radiated directly to outer space. In atmospheric shots, the loss is not so great because of scattering.	1964
L.	The thermal effects of ground and low altitude bursts are well understood by virtue of the weapons tests.	1964

L.	The thermal effects for extremely high altitudes (more than 31 miles) and outer space shots are presumably known by virtue of theory, but the intermediate altitudes are difficult to explain and the empirically derived scaling laws are not too reliable.	1964
L.	The understanding of the thermal pulse shape at altitudes up to 31 miles is not too great.	1964
L.	The ignition radius for dry pine needles can vary from less than 1 mile for low visibility conditions to approximately 20 miles where the visibility is 50 miles and the burst is above a snow surface.	1964

Appendix D - Conclusions: Response of Target Elements to Direct Nuclear Thermal Radiation

Source Code	Conclusions	Date
I.	Inadequate values are available for thermal yield of surface bursts and critical ignition energies of kindling fuels for megaton range weapons.	1960
K.	Concerning ignition, the only effect of genuine concern appears to be the ignition of thin, cellulosic kindling fuels, i.e., materials igniting at less than about 20 cal./cm^2.	1964
K.	The radiant exposure required to ignite a material is a function of exposure duration, i.e., the efficiency depends upon rate of delivery of energy.	1964
K.	Radiant exposure values for sustained ignition of typical kindling fuels is on the order of 10 cal./cm^2. Simulation of irradiance levels for high altitude bursts is difficult to achieve.	1964
K.	At the present time there is insufficient yield/altitude scaling information to permit detailed simulation of thermal pulses from high altitude bursts.	1964
K.	The area of exposure and the geometry (position) of the exposed material are important single factors effecting ignition.	1964
Q.	The experts differ on their estimate of ignition threshold of common kindling fuels.	1964
L.	No studies have been made on the effect of overlapping thermal pulses on materials.	1964

Appendix E - Conclusions: Target Vulnerability

Source Code	Conclusions	Date
D.	Nuclear weapons fires will be the source of greatest damage in future nuclear wars.	1962
D.	The ratio of damage by fire to damage by blast increases with weapon yield.	1962
I.	Inadequate information is available concerning the actual distribution of kindling fuels.	1960
C.	The pattern of fallout without the occurrence of mass fire may be predicted with a reasonable degree of accuracy.	1959
C.	The effects of a mass fire (convection column) on associated radioactive fallout is known only in a theoretical way. No large scale experiments are available.	1959
C.	A strong, fire induced convection column can have a marked effect on radiological fallout - as indicated by small scale, wind tunnel experiments.	1959
C.	Experimental results are not directly applicable to open-air conditions.	1959
J.	From a fire standpoint the high-altitude thermal attack with a high-yield weapon is most destructive followed by airbursts and surface bursts in that order.	1964
K.	Fire susceptibility in inhabited areas appears to depend primarily on the kind and distribution of interior kindling fuels.	1964
K.	Interior fuel ignition is relatively insensitive to weather.	1964
K.	Ignition and burning of exterior fuels depends heavily on the weather.	1964

K.	Urban areas are believed to be quite vulnerable to fire from a nuclear thermal pulse. One home in three would be involved in fire where newspapers or similar weight kindlings are ignited.	1964
P.	Shielding is an important factor in determining ignition possibilities following a heat flash. Shielding effects survival rate of people also.	1964
P.	Window drapes or curtains increase the chances of interior fires from thermal flashes.	1964
P.	Streets perpendicular to the direct line of flash will suffer maximum numbers of interior ignition.	1964
P.	In general fire risk was far greater for incendiary bombing raids than for high explosive bombing raids.	1964
P.	Weather was not an important factor in determining incidence and fire spread during the London fly bomb raids of summer 1944.	1964
P.	At Hiroshima and Nagasaki the main fire area extended about $1\frac{1}{4}$ miles from ground zero and the blast damage for another $\frac{1}{2}$ mile. There were only isolated fires in the area affected only by blast.	1964
P.	There is little direct evidence to support the contention that most of the fires in Hiroshima were caused by blast damage.	1964
P.	Thermal flash caused the major fires in Hiroshima.	1964
Q.	For the average American city, the high altitude incendiary weapon would be effective 1/3 of the time, partly effective 1/3 of the time and ineffective 1/3 of the time, based upon frequency of cloudy days.	1964
R.	Combustibles in buildings will be ignited by nuclear weapons as a result of thermal radiation or blast effects.	1964

R.	Shelter buildings can be ignited during fallout period from nearby burning structures or accidental fires.	1964
R.	Most shelter structures would be in danger of fire from ignition of buildings close by.	1964
R.	Shelter buildings may be classified as (1) fire limiting, (2) suppression dependent, and (3) untenable.	1964
L.	Ground bursts would be required to destroy hardened targets (counterforce attack) which would reduce the area of initial ignitions.	1964
L.	Because of the spreading of fires and the large ignition areas, the accuracy of the weapon is not a critical factor in the weapons effectiveness in setting fires.	1964
L.	There have been some attempts to study the direct relation of season of the year to the peacetime threat of fires.	1964
L.	In wartime, two additional effects of weather are the modification of the nuclear thermal pulse and the vulnerability of the blast.	1964
L.	It can be assumed that in any future attack launched on a clear day the ratio of the number of primary fires to the number of secondary fires will be greater than it was in the atomic attack on Japan since the thermal radiation effects cover proportionately larger areas than blast damage from the megaton yield.	1964
L.	Practically no information exists concerning the importance and statistical distribution of vegetation near structures.	1964

Appendix F - Conclusions: Fire Development and Spread

Source Code	Conclusions	Date
F.	Extreme temperatures may be reached in two or three minutes following multiple ignition in a prepared fuel bed.	1964
F.	Temperature may account for the behavior differences between large and small fires.	1964
F.	For some fires, fire spread from radiation is of minor importance.	1964
D.	Primary fire will be a significant factor in the initiation of mass fires in modern cities as a result of nuclear weapon attack.	1962
D.	Secondary fires were important in development of mass fires from the nuclear attacks on Japan. (Note: This is in opposition to the conclusions made by Stanbury, British paper.)	1962
F.	Fire convection columns block ambient air flow.	1964
F.	Eddy circulations are important in the development of fire whirlwinds and possibly fire storms.	1964
E.	In cities, fire spread depends more on spacing and type of construction than on weather.	1963
E.	City fires spread at about the same rate as forest fires.	1963
E.	Fire spread over periods of 6 hrs. or longer, is much slower than popularly assumed.	1963
E.	Over long periods of time, fires travel fastest over level ground. Upslope next fastest; down slope slowest.	1963
E.	Rate of spread depends on the length of time over which the spread is measured.	1963

E.	Conflagration head fire moves, on the average, 3 times the rate of the flanks and 7 times as fast as the rear.	1963
I.	Inadequate information is available on the physics of large scale fire spread.	1960
I.	Two classes of physical research require more study. These are: (1) prediction of initial ignition area and (2) prediction of fire spread area from initial ignition area.	1960
K.	Even after missing information on ignition has been determined, we still do not know if a serious fire will develop or the resulting fire will spread.	1964
K.	Fire behavior in uninhabited areas following nuclear attack would be basically no different from the behavior of wildland fires in peacetime.	1964
N.	Critical periods of fire weather are associated with a relatively few synoptic weather patterns and types.	1964
N.	This study identifies the periods when weather conditions favor fast-spreading, high intensity fires.	1964
N.	Fire damage resulting from nuclear or incendiary weapons attack will depend upon fuel type and availability, and weather influencing spread and intensity of initial fire and peripheral spot fires.	1964
N.	Civil Defense planning will benefit from the snow cover probability maps developed for each week, December through March.	1964
N.	This study covers critical fire weather patterns on a broad synoptic scale. Local effects are not included.	1964
N.	Civil Defense planning will benefit from the information developed on monthly levels of fire danger experienced at each of the 89 cities for the 10-year period.	1964

N.	Using the descriptions of fire weather patterns and types described in this report, fire weather meteorologists are provided with a better means of anticipating periods of critical fire weather in local areas.	1964
P.	The incidence of secondary fires (from blast) was probably not high enough to cause a fire storm even in such a flammable city as Hiroshima.	1964
Q.	Mass fires are more likely in built-up urban areas than in rural areas.	1964
Q.	The potential ignition area cannot be considered as a single fire area "engulfed in flame" since the controlling factors are the occurrence and size of the fuel areas rather than the ignition range of the weapons.	1964
L.	Unlike blast, fires may spread from the areas ignited by the individual missiles and may coalesce into a single firestorm or conflagration.	1964
L.	There is still very little known about the coalescence of fires into mass fires.	1964
L.	Once a mass fire is started, its spread is dependent on winds, other climatological factors, and the distribution and condition of heavier fuels.	1964
L.	In a U.S. city it is probable that primary fire rather than secondary fire will be the major problem in the event of a nuclear weapon attack.	1964
L.	In most cases, fire in structures would not be started directly by the thermal pulses, rather it would develop from ignited kindling fuels in proximity to or within the structures.	1964
L.	Densities of ignition points in the initial ignition radius varies with distance from ground zero and type of fuel and this effects fire growth.	1964

Appendix G - Conclusions: Fire Spread and Damage Assessment Models

Source Code	Conclusions	Date
A.	The tables in the Forest Service burnout estimation report are rough approximations of the values which can be calculated more precisely from the formulae in the Broadview Report.	1961
A.	For bomb sizes less than 1 megaton, the 1 megaton data is used.	1961
A.	For determining burn-out size for bomb yields over 10 megaton (max. on table), use a straight line projection from the three megaton estimate through the 10-megaton figure to bomb sizes up to 20 megatons.	1961
G.	Flame I does not attempt to predict fire intensity or damage resulting from the fire.	1964
G.	Flame I is a damage assessment program to apply soon after a nuclear attack and for hypothetical fire spread studies.	1964
G.	Flame I estimates which land areas, on a nation-wide basis, would be affected by fire spread following attack.	1964
G.	Relevant factors used by Flame I in considering extent of fire spread: a. weapons information b. geographical information c. weather information	1964
G.	Flame I weapons information must include: a. geographic portion of ground zero b. weapon yield c. height of burst d. month detonated	1964
G.	Geographic information for Flame I must include a map which shows fuel distribution and fire barriers in the area of interest.	1964

G.	Weather information for Flame I must describe the weather conditions in the area of interest.	1964
G.	The Flame I fire spread simulator (model) attempts to predict fire spread from an attack by estimating for each grid rectangle on a map, the probability that it is burned. Weather, fuels, and fire barriers are considered along with weapons information.	1964
G.	The "1957 Forest Damage Assessment" study made by the Forest Service is the basis for the monthly estimates of fuel characteristics for each month.	1964
I.	The Stanford Research Institute Damage Assessment System is primarily concerned with damage due to nuclear effects rather than fire damage to rural areas.	1964
I.	The fire spread model developed in this study is a descriptive model of fire spread that relies on the judgment of individuals experienced with large scale fire.	1960
I.	Standford Research Institute damage assessment method uses 24,000 "Standard Locations" based primarily on population and recognize that -- "the possible percent of error in estimating damage in rural areas is high."	1960
I.	Damage Assessment Systems (up to this report) consider either damage to natural resources or damage to population and urban targets.	1960
L.	Existing fire damage models do not discuss the total damage which would be created under various assumed targeting doctrines. They consider only attack by a single weapon.	1964
L.	In general, laboratory studies of mass fires are difficult to formulate and test.	1964

Appendix H - Conclusions: Vulnerability of Humans

Source Code	Conclusions	Date
B.	Extreme carbon monoxide concentrations are to be expected in large-scale fires burning out of doors.	1961
B.	If shelter ventilation systems are to be operated during a fire, shielding of intake vents from radiant heat should be considered to insure passage of cool air.	1961
B.	Shelter vents may not need to be closed for more than an hour or so during mass fires if they are located so that they will not be covered by rubble.	1961
B.	Home shelter vents located just outside the residence will be of little value since toxic gasses may be found in these locations.	1961
F.	Lethal concentrations of noxious gasses occur in the combustion zone.	1964
J.	Fire will be a significant factor in causing injuries, loss of life, and destruction of property immediately following a nuclear attack. Firestorms may develop in densely populated areas.	1964
K.	Major blast effects will be on personnel, equipment, facilities, travel routes, and communications.	1964
P.	A greater loss of life resulted from the fire storm raids on Germany (9 deaths per bomb-ton) than non-fire storm raids (1.3 deaths per bomb-ton).	1964
P.	In every case where fire storms were experienced in German cities, the loss of life was heavier than in raids that involved mostly blast effects and high explosive bombs.	1964

Q.	Only a small portion of the population at risk will be killed as a result of mass fires, judging from past experience.	1964
Q.	Judging from past experience the rate of development of large fires will be sufficiently low to permit control or movement of people to areas of relative safety (currently true?).	1964
R.	Fallout shelter occupants will be exposed to fire from several sources.	1964
L.	A considerable portion of the population of most cities would likely survive attack.	1964
L.	In most studies of weapons effects, little attention has been paid to the combined effects of thermal, radiological and blast damage.	1964
L.	The temperature within underground shelters during a mass fire is critically dependant on the conduction of heat from the rubble above, through the soil, concrete, steel, wood, or other intervening materials.	1964

Appendix I - Conclusions: Countermeasures

Source Code	Conclusions	Date
D.	Fire break effectiveness is increased by a factor of two when fire retardant coatings are used.	1962
J.	Pre-attack measures to reduce the number of fires must be taken.	1964
J.	Conduct cleanup campaigns.	1964
J.	Prohibit littering by ordinances.	1964
J.	Raise minimum building maintenance standards.	1964
J.	Raze dilapidated structures.	1964
J.	Require use of fireproof materials in construction by revising building codes.	1964
J.	Establish smoke and/or aerosol blankets over urban areas.	1964
J.	Coat windows with materials that will darken or smoke when exposed to high temperatures.	1964
J.	Coat exterior kindling points with smoke-producing substances.	1964
J.	Use fire-resistant paints on structures.	1964
J.	Use metal ribbon or fine-mesh screens on windows.	1964
J.	Install sprinkler systems in structures.	1964
J.	Provide and equip fallout and blast shelters for the populace.	1964
J.	Coat windows of structures and vehicles with thermal-activated protective coatings.	1964
J.	Use ignition-resistant fabrics, skin creams, and eye protectors.	1964

J.	Integrate plans for mitigation and containment of fires in city planning.	1964
J.	Two of the four pre-attack measures analyzed appear particularly promising; conduct cleanup campaigns in cities and develop and apply coatings that turn opaque or smoke when heat is applied.	1964
J.	More detailed and extensive cost-effectiveness studies of active and passive fire defenses will be necessary before their effects upon civil defense policy and doctrine can be adequately evaluated.	1964
J.	Cost-effectiveness analysis procedures used have potential for further use. These should be studied.	1964
K.	Fire vulnerability of population centers can be lessened by extensive pre-attack planning and training in implementing the self-help fire-fighting concept.	1964
Q.	In planning a fire defense program against nuclear attack, the removing or covering of ignitable materials is equally as important as the development of fire control capabilities.	1964
L.	Since the initial fires would be started in kindling fuels, a general cleanup campaign would reduce the ignition point and hence the probability of the development of mass fires.	1964
L.	Stricter building and fire codes might aid in preventing group fires from developing into mass fires.	1964

Appendix J - Conclusions: Organizing to Suppress Post-Attack Fires

Source Code	Conclusions	Date
J.	Professional urban fire departments will not have the resources required to effectively fight the post-attack fires.	1964
J.	The cost of maintaining conventional fire-fighting forces adequate to handle any post-attack fire situation would be prohibitive.	1964
J.	Assistance from the general public, properly trained and equipped, is necessary to combat fires resulting from attack.	1964
J.	Equip and train building tenants for self-help firefighting.	1964
J.	Train the citizenry in fundamentals of fire-fighting. Provide inducements.	1964
J.	Make all firefighting teams self-sufficient.	1964
J.	Standardize on a low-cost, low-pressure, fog nozzle for use with garden hoses.	1964
J.	Establish a system of water storage tanks for supplemental water.	1964
J.	Existing radio systems would be completely inadequate to handle communications in the attack situations described.	1964
J.	Install many more radio channels for use in nuclear emergencies. Develop improved reconnaissance and surveillance techniques for assessing the fire situation.	1964
J.	Encourage utilities to develop loop systems to avoid interrupting service due to blast damage.	1964
J.	Equip fire suppression groups with radiological monitoring equipment.	1964

K.	Even the most heroic efforts of professional fighters would be in vain when fighting the multitude of fires resulting from nuclear weapons attack - too many fires would result - scattered over too large an area.	1964
M.	Mass fire must be prevented by extinguishing building fires before they can join with other fires.	1964
M.	The large number of ignitions resulting from an attack cannot be controlled by the manpower (fire services) and equipment available during peacetime.	1964
M.	Organized public firefighting agencies, with or without assistance from civilian population, are incapable of suppressing a GOING urban mass fire.	1964
M.	Room fires consisting of burning furniture items can be controlled by trained individuals properly equipped and operating in pairs.	1964
M.	Due to the possibility of radioactive fallout, only a relatively-short period of time may be available to extinguish the multiple ignitions resulting from a nuclear burst.	1964
M.	Maximum utilization of effort with emphasis on minimum use of extinguishing media and equipment will be needed to prevent development of mass fires.	1964
M.	The five-gallon stirrup pump was found to be the most satisfactory piece of self-help extinguishment equipment.	1964
M.	Single-room dwelling flashover fires can be effectively controlled with 15 gallons of water using 18 gpm application with a 60° spray pattern.	1964
M.	Minimum water usage necessary to accomplish the job should be stressed during emergencies.	1964

M.	Operational fire defense problems resulting from nuclear emergency would include: a. Command and staff functions b. Communications c. Logistics d. Traffic control e. Water supplies	1964
M.	Decentralization of command with alternate command posts at each level is needed.	1964
M.	Airborne observers may be used to quickly assess damage levels and make tactical decisions regarding commitment of fire forces.	1964
M.	Mobile radio transmitters and emergency land lines will be the basis for establishing primary contacts.	1964
M.	Civilian vehicles should be utilized to transport fuel and water in areas of operation.	1964
M.	Personnel and emergency apparatus will be difficult to move over any distance following an attack.	1964
M.	All sources of water should be inventoried and identified for possible use during emergencies.	1964
O.	Too much "red tape" required to acquire needed equipment from CD through the "Matching Fund" program.	1964
O.	There is a general atmosphere of antagonism or indifference between fire services and CD.	1964
O.	Fire department members are reluctant to assume appointed positions at state level (CD) because they must relinquish their Civil Service status.	1964
O.	With regard to financial support for nuclear disaster programs: It is difficult to convince taxpayers to commit community funds for disaster (nuclear) which has never occurred in this country, which has a very complex probability factor, and which quite often he believes will destroy him if it does occur. (Reviewers italics)	1964

O.	Planning is a vital factor for increasing the effectiveness of small communities to withstand the effects of extreme emergency conditions.	1964
O.	Small communities can organize effectively for natural and nuclear disasters.	1964
O.	From preliminary studies disaster simulation seems feasible for small community application.	1964
O.	Training courses for handling of disasters must be taught by qualified individuals having practical experience.	1964
P.	Many of the small fires, described as "debris" fires, that result from a high explosive attack can usually be controlled by fire guards acting independently.	1964
Q.	The most serious complication introduced by modern weapons is the threat of fallout that could hamper firefighting or remedial movement.	1964
R.	Shelter buildings presently in use are predominently of fire resistant construction and a self-help approach to extinguishment of small fires would be mostly successful.	1964
L.	Professional fire fighters would probably be most effective at that stage where individual structures are afire but the flames have not yet coalesced into mass fires.	1964
L.	Buildings destroyed by blast would create barriers, seriously handicapping the work of firemen and rescue workers. This problem has never been studied.	1964

Appendix K - Conclusions: Suggesting Additional Research

Source Code	Conclusions	Date
F.	Field scale fires can be replicated when tests are conducted under like air mass conditions and with similar fuels.	1964
F.	Wildland fuels can be used to simulate many urban conditions.	1964
F.	Some observations during these field tests suggest conditions that are not evident in small scale or laboratory fires.	1964
F.	The tests completed to date are not considered as mass fires due to their limited size.	1964
N.	Civil Defense planning will be improved through more accurate predictions of critical fire weather periods.	1964
L.	The Office of Civil Defense should recognize that the protection of people and property from fires caused by a nuclear attack presents unique problems. They are not necessarily identical with those of the Forest Service, urban fire departments, fire underwriters, the basic researcher, or even the planner of military offense strategies. Although the Office of Civil Defense must use the wealth of experience and the research capabilities of these groups wherever applicable, it should develop in detail its own fire research program based upon goals which will lead to a feasible accomplishment of civil defense missions.	1964
L.	Formulation of Quantitative Goals - As a prime prerequisite to all fire research sponsored by the Office of Civil Defense, an analysis should be made outlining specific quantitative goals which, if achieved, would materially assist in the conduct of the civil defense missions. As a simple example, a goal of civil defense might be to estimate the earliest possible time that shelter occupants could be sagely removed from shelters within the fire damaged areas. Starting from this goal,	1964

important parameters could be identified, giving specific direction to the research. Such parameters, for this case might be the temperature history of the fire, the radioactivity of the area (if any), the amount of rubble in the streets, and the like. Although research effort should be expended on detailed studies of these unknowns, it is not expected that they will be well understood for some time. Parametric studies might establish bounds which would give initial results pending more scientifically precise investigations.

L. Strategy and Tactics - In the past, little effort has been applied to the importance of the strategy and tactics of a possible attack from the standpoint of fire damage. A recognition of these inputs is necessary for understanding the fire threat posed by nuclear weapons. In particular, limited to the following: a description of the thermal effects of multiple weapons on a target area; a study of the importance of timing of an attack on the parameters affecting the vulnerability of the entire United States simultaneously; an investigation of the importance of warning to civilians and professional firefighters, additional research on the effect of altitude on the thermal partitioning of energy and the pulse shapes of weapons, particularly for the intermediate altitudes (10 km to 80 km--6 to 50 miles) 1964

L. Weapons Phenomena--Analysis of the effects of nuclear weapons will be incomplete unless further research effort is expended on certain weapon phenomena. Strong convection currents from mass fires may seriously alter the results predicted from detailed fallout models. There are also indications that with large weapons, the resulting fires may be extinguished by the follow-on blast wave. Furthermore, the direct effects of atomic bursts on clouds and fog is practically unknown. 1964

L. Response of Materials--The effects of actual and simulated weapons pulses on materials is perhaps the most thoroughly understood phenomenon in the entire fire research area. Even here, however, work remains to be done. In particular, investigation 1964

is required on the effects of extremely short, high intensity pulses such as would be experienced from a high altitude burst. Also, study is needed on the effects on materials of overlapping thermal pulses from more than one weapon.

L. Urban/Rural Interactions--Almost invariably, the study of the fire potential of weapons has been restricted either to forested areas or to urban areas. A unified study is required which will consider the effects radii of weapons, the size of cities, and the interface between the cities and forested areas to give an indication of the interaction between urban and rural fire susceptibility, fire behavior, and fire defense. 1964

L. Ignition Points--More precise definitions of the important ideas of ignition points and ignition densities should be made, and parametric studies should be conducted on their variation with attack parameters. A study should be undertaken to develop these quantities into factors which will apply to the ultimate aims of civil defense. 1964

L. Japanese Data--A systematic effort should be made to interpret (both linguistically and mathematically) the wealth of Japanese experience with conflagrations and to apply the results to the study of mass fires in the United States. 1964

L. Coalescence--Before firestorms and other fire processes can be fully understood, much more information is required on the problem of the coalescence of fires, both within the area of effects of a single nuclear weapon and between such areas in the case of attacks with more than one weapon on a target. 1964

L. Countermeasures--Although it is evident that effort should be continued on the development of passive countermeasures for the entire spectrum of potential fires, an equally important effort should be directed toward methods for getting promising countermeasures widely accepted by the public. Most countermeasures would not be effective unless incorporated on a large scale. Since past experience has shown that the usual public reaction is one of apathy, legal steps may 1964

be required to accomplish vigorous public participation. This may necessitate more stringent legal restrictions on building densities and other construction codes, as well as laws to allow firefighters legal protection when choosing the most effective method of attacking a fire.

L. Functional Systems--Studies should be made of the fire vulnerability of functional systems, such as the power industry, agriculture, and transportation and communication systems. In particular, the susceptibility of the petroleum industry to nuclear thermal radiation, fire, and fire spread should be considered. With the exception of studies on the vulnerability of military installations, no studies apparently have considered the vulnerability of a functional system to the particular threat of nuclear fires. 1964

Appendix L - Miscellaneous Conclusions

Source Code	Conclusions	Date
H.	Good maps of project size fires (300 acres +) can be provided using presently available infrared equipment.	1962
H.	The infrared system used must have the capability of penetrating dense smoke covering large areas.	1962
H.	Maps are sufficiently accurate to map the perimeter with respect to terrain features.	1962
H.	It is not possible to accurately determine the effectiveness of infrared scanners in seeing small heat sources through varying smoke densities associated with forest fires.	1962